Atmospheric data for geodetic applications

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- Troposphere has a significant impact on GPS or satellite altimetry measurements.
- Short-time mass variations in the atmosphere influence the Earth’s gravity field.
- Changes in the Earth’s rotation vector and geocenter due to atmospheric variations.
- Evaluation of e.g. space bourne observations.
- Good knowledge about the atmospheric impact on measurements improves the quality of the satellite observations.
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Global atmospheric reanalysis models

- Use of global atmospheric reanalysis models to analyze the main processes and dynamics in the atmosphere
- Numerical model for the time evolution of atmospheric processes
- Assimilation of various observations (satellite, radiosondes, terrestrial) to obtain an estimate of the atmosphere which is consistent with both the model and the observations
- Huge computational effort (for ERA-Interim: between $10^6$ and $10^7$ observations per day)
- Used for many scientific applications (input data for numerical weather prediction, atmospheric downscaling, investigation of atmospheric processes, ...)

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2011-09-28
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**Validation is mandatory due to model character!**
## Parameters of the reanalyses

<table>
<thead>
<tr>
<th>Reanalysis</th>
<th>Institution</th>
<th>Available time-period</th>
<th>Horizontal Resolution</th>
<th>Vertical levels</th>
<th>Top level</th>
<th>Temporal resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERA-Interim</td>
<td>ECMWF</td>
<td>1979 - present</td>
<td>T255 (≈ 78 km)</td>
<td>60</td>
<td>0.1 hPa</td>
<td>6 h, 1 d, 1 m</td>
</tr>
<tr>
<td>MERRA</td>
<td>NASA</td>
<td>1979 - present</td>
<td>1/2° × 2/3°</td>
<td>72</td>
<td>0.01 hPa</td>
<td>6 h, 1 d, 1 m</td>
</tr>
<tr>
<td>CFSR</td>
<td>NCEP</td>
<td>1979 - present</td>
<td>T382 (≈ 38 km)</td>
<td>64</td>
<td>0.26 hPa</td>
<td>1 h, 6 h, 1 m</td>
</tr>
</tbody>
</table>
Validation methods

1. Validation against observations (GPCC, GPCP, CRU, ...)
2. Analysis of the closure of modelled water budgets
   - Terrestrial water balance
     \[
     \frac{dS}{dt} = P - E - R
     \]
   - Atmospheric-terrestrial water balance
     \[
     \frac{dW}{dt} = E - P - \nabla \cdot Q
     \]
   - Continental-oceanic water balance
     \[
     (P - E)_{\text{land}} \approx -(P - E)_{\text{ocean}}
     \]
   - Long-term budgets (⇒ negligence of the tendency terms)
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Distribution of gauges in the precipitation observations

a) GPCC, 1989
b) GPCC, 2006
c) CPC, 1989
d) CPC, 2006

[gauges/gridcell]
## Evolution of the number of gauges per continent

<table>
<thead>
<tr>
<th>Continent</th>
<th>CPC Jan 1989</th>
<th>CPC Dec 2006</th>
<th>CPC Jan 1989</th>
<th>CPC Dec 2006</th>
<th>Area [km²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>North America</td>
<td>10066</td>
<td>9609</td>
<td>6703</td>
<td>745</td>
<td>19,388,969</td>
</tr>
<tr>
<td>South America</td>
<td>6093</td>
<td>1314</td>
<td>4267</td>
<td>390</td>
<td>17,797,363</td>
</tr>
<tr>
<td>Europe</td>
<td>1050</td>
<td>1236</td>
<td>9649</td>
<td>4481</td>
<td>5,764,224</td>
</tr>
<tr>
<td>Africa</td>
<td>419</td>
<td>467</td>
<td>3380</td>
<td>479</td>
<td>30,046,428</td>
</tr>
<tr>
<td>Asia</td>
<td>1887</td>
<td>1275</td>
<td>2509</td>
<td>1315</td>
<td>37,391,906</td>
</tr>
<tr>
<td>Australia</td>
<td>5854</td>
<td>5534</td>
<td>5407</td>
<td>401</td>
<td>7,721,577</td>
</tr>
</tbody>
</table>
Observed and modeled precipitation

Difference in the annual mean precipitation with respect to GPCC

- a) CRU − GPCC
- b) CPC − GPCC
- c) ECMWF − GPCC
- d) MERRA − GPCC
- e) CFSR − GPCC
Observed and modeled precipitation

Relative precipitation with respect to GPCC in units of [mm/day].
Variability of models and observations

a) Obs, Prec
b) Obs, T

c) Reana, Prec
d) Reana, T

[mm/day]

[°C]
### Long-term mean water cycle components

Estimates are given in units of $[10^{15} \text{ kg/year}]$

<table>
<thead>
<tr>
<th></th>
<th>ERA Interim</th>
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<th>CFSR</th>
<th>Trenberth, 2007</th>
<th>Oki, 2006</th>
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<tbody>
<tr>
<td>$P_{\text{land}}$</td>
<td>120.3</td>
<td>112.9</td>
<td>126.7</td>
<td>113</td>
<td>111</td>
</tr>
<tr>
<td>$E_{\text{land}}$</td>
<td>83.5</td>
<td>85.1</td>
<td>73.3</td>
<td>73</td>
<td>65.5</td>
</tr>
<tr>
<td>$P_{\text{ocean}}$</td>
<td>415.7</td>
<td>383.8</td>
<td>471.6</td>
<td>373</td>
<td>436.5</td>
</tr>
<tr>
<td>$E_{\text{ocean}}$</td>
<td>451.1</td>
<td>413.0</td>
<td>478.9</td>
<td>413</td>
<td>436.5</td>
</tr>
<tr>
<td>$R$</td>
<td>44.9</td>
<td>28.2</td>
<td>37.7</td>
<td>40</td>
<td>45.5</td>
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<tr>
<td>$(P - E)_{\text{land}}$</td>
<td>36.6</td>
<td>28.4</td>
<td>53.0</td>
<td>40</td>
<td>45.5</td>
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<tr>
<td>$(P - E)_{\text{ocean}}$</td>
<td>-35.4</td>
<td>-29.8</td>
<td>-7.3</td>
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<td>$\vec{\nabla} \cdot \vec{Q}_{\text{land}}$</td>
<td>31.8</td>
<td>41.0</td>
<td>33.4</td>
<td>40</td>
<td>45.5</td>
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Time-evolution of the water budgets

Atmospheric moisture fluxes (grey) vs. terrestrial water budgets (black)
Latter results showed large differences in the reanalyses’ terrestrial water budgets (i.e. $P - E$)!
Evaluation of GRACE using atmospheric data

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**Approach:** Use atmospheric moisture fluxes to overcome the uncertainties in \( P \) and \( E \).
Evaluation of GRACE using atmospheric data

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**Approach:** Use atmospheric moisture fluxes to overcome the uncertainties in $P$ and $E$.

Atmospheric-terrestrial water balance:

$$\frac{d W}{d t} = E - P - \vec{\nabla} \cdot \vec{Q}$$

Over longer time-scales, $\frac{d W}{d t} \approx 0$

$$\Rightarrow \quad \vec{\nabla} \cdot \vec{Q} = E - P$$

$$\Rightarrow \quad \frac{d S}{d t} = -\vec{\nabla} \cdot \vec{Q} - R = \frac{d M}{d t}$$
Evaluation of GRACE using atmospheric data

Amazon basin

[mm/month]

GRACE  ERA Interim  MERRA  CFSR

2004  2005  2006  2007  2008  2009  2010

−200  −150  −100  −50  0  50  100  150  200
Evaluation of GRACE using atmospheric data

Mississippi

[mm/month]

2004 2005 2006 2007 2008 2009 2010

−100 −75 −50 −25 0 25 50 75 100
Evaluation of GRACE using atmospheric data

Ob basin

[mm/month]

2004 2005 2006 2007 2008 2009 2010

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Conclusion

- The analyzed atmospheric models allow comprehensive studies of especially tropospheric processes and dynamics.
- But we also have to take into account their shortcomings and uncertainties.
- Reanalyses are a reasonable compromise between models and observations.
- Ensemble estimates of atmospheric quantities are a reasonable basis for evaluating e.g. water storage changes from GRACE.
- The quality of the models has major impact on the reliability of especially satellite observations.
- Improvements in the models’ performance can be expected (assimilation schemes, number and quality of observations, ...).
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Thank you for your attention.